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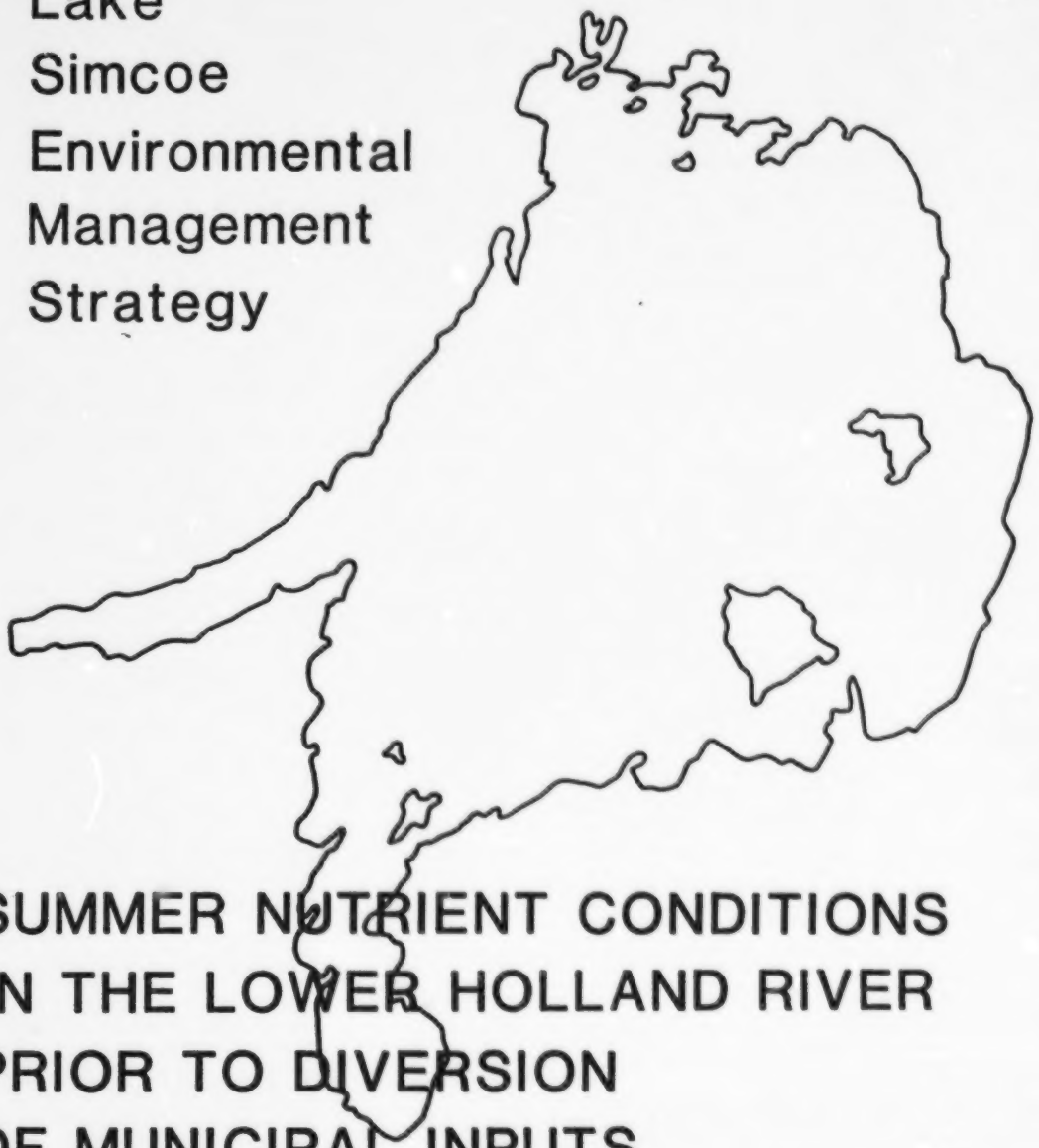

SUMMER NUTRIENT CONDITIONS IN THE LOWER HOLLAND RIVER PRIOR TO DIVERSION OF MUNICIPAL INPUTS

TECHNICAL REPORT B.3

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LAKE SIMCOE ENVIRONMENTAL MANAGEMENT STRATEGY

SUMMER NUTRIENT CONDITIONS IN THE LOWER HOLLAND RIVER PRIOR TO DIVERSION OF MUNICIPAL INPUTS

Prepared for the Steering Committee of the Lake Simcoe Environmental Management Strategy

by

R. Angelow[1]

G. Robinson[2]

[1]Ontario Environmental Services (O.E.S.)
5 Feller Road, Weston
Ontario M9R 3R9

[2]Ontario Ministry of the Environment
Water Resources Branch
Aquatic Ecosystems Section
Box 213, Rexdale, Ont.
M9W 5L1

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LAKE SIMCOE ENVIRONMENTAL MANAGEMENT STRATEGY

FOREWORD

This report is one of a series of technical reports prepared in the course of the Lake Simcoe Environmental Management Strategy (LSEMS) studies. These studies were initiated in 1981, as directed by the Cabinet Committee on Resources Development, to investigate methods of reducing phosphorus loadings from the Holland Marsh.

The studies are under the direction of the LSEMS Steering Committee, which is comprised of representatives of the following agencies:

- Ministry of Agriculture and Food
- Ministry of the Environment
- Ministry of Natural Resources and
- South Lake Simcoe Conservation Authority

This Committee expanded the SCOPE of these studies to include the total Lake Simcoe basin. This change in study mandate was made to place all sources of phosphorus loadings to Lake Simcoe into perspective. Thus the following sources were investigated:

- agricultural and rural runoff
- urban runoff
- streambank erosion and
- sewage treatment facilities.

In order to develop practical abatement measures to minimize such inputs, studies were initiated to inventory, quantify and target areas with respect to soil loss, livestock and farming operations, streambank erosion and urban runoff.

The Committee also approved Lake Simcoe studies to establish current information on lake water quality and aquatic plant growth. Such studies were required to establish baseline conditions to compare future water quality conditions. These are expected to improve, because of the following:

- municipal and provincial efforts to reduce phosphorus loadings from sewage treatment facilities and
- because of expected changes to more environmentally acceptable land use practices by developers and farmers to reduce inputs from non-point sources.

Questions with respect to the contents of this report should be directed to:

Regional Director, Central Region
Ministry of the Environment
7 Overlea Boulevard, Toronto, Ontario, M4H 1A8

or

General Manager
South Lake Simcoe Conservation Authority
120 Bayview Avenue, Box 282
Newmarket, Ontario, L3Y 4X1

DISCLAIMER

The material presented in these reports is analytical support information and does not necessarily constitute policy or approved management priorities of the Province and/or the South Lake Simcoe Conservation Authority. Interpretation and evaluation of the data and findings, should not be based solely on this specific report. Instead they should be analysed in light of other reports produced within the comprehensive framework of this environmental management strategy.

Reference to equipment, brand names or suppliers in this publication is not to be interpreted as an endorsement of that product or supplier by the authors, the Ministry of the Environment or the South Lake Simcoe Conservation Authority.

ABSTRACT

Nutrient concentrations in the lower Holland River were monitored during the summers of 1982 and 1983 to provide baseline information prior to the diversion of major municipal phosphorus inputs. Concentrations of phosphorus and nitrogen compounds were generally highest in the Holland River East Branch and lowest near the river mouth.

Since the introduction of nutrient control measures and detergent-P legislation in Ontario during the early 1970's, improvements in water quality throughout the lower Holland River were apparent. Mean concentrations of total phosphorus, soluble reactive phosphorus, and chlorophyll a were significantly lower in 1982 compared to water samples collected during 1971 ($P<0.05$). For example, in 1982 the average total and soluble reactive P concentrations near the river mouth were 218 and 101 µg P/L, respectively, corresponding to 40 and 49 percent reductions. In 1983, mean soluble reactive P concentrations in the river were not significantly lower than those recorded in 1971. In 1983, Cook Bay had the lowest mean concentrations of total P (50 µg P/L), soluble reactive P (16 µg P/L) and corrected chlorophyll a (4 µg/L) found in this study, corresponding to 75, 86 and 85 percent reductions, respectively.

Elevated concentrations of phosphorus, iron and manganese in the lower Holland River and in water impounded from the river by the experimental enclosures demonstrated that during the summer months the river sediments can contribute significant amounts of phosphorus to the overlying water. The internal phosphorus inputs appear to be regulated by oxidation-reduction (redox) potential. Intact sediment cores taken from the Holland River and Holland River East Branch, showed a greater potential for total phosphorus regeneration in the Holland River East Branch sediments. Further recovery of the lower Holland River and Cook Bay may depend upon the extent of phosphorus feedback from the bottom sediments.

The diversion of Newmarket and Aurora sewage will reduce river flows. This could increase internal phosphorus loading through stagnation. The expected water quality improvements in Cook Bay could be delayed or

INTRODUCTION

Eutrophication models help define relationships that are useful in predicting the phosphorus dynamics of freshwater lakes in response to management options. However, predicting the recovery of shallow eutrophic lakes to reduced nutrient inputs depends on our ability to identify processes which influence internal regeneration (Medine and Anderson 1983, Ryding and Forsberg 1977, Lean et al. 1975). Phosphorus supply is the principle determinant of phytoplankton production in most lakes and is functionally modified by lake morphometry, light and other influences (White et al. 1981, Nalewajko, Lee, and Shear 1981, Oglesby 1977, Schindler 1975). Using seasonal budget calculations, it is difficult to identify the active mechanisms regulating sediment nutrient release (Ryding and Forsberg 1977). In addition, few data sets can accurately estimate the return of phosphorus from the sediments of enriched lakes (Prepas and Rigler 1982).

The importance of sediment phosphorus regeneration on the recovery of highly eutrophic shallow lakes has been frequently observed (Lijklema and Hieltjes 1982, Bostrom et al. 1982, Ahlgren 1976, Ryding and Forsberg 1977). The recovery of these lakes, after sewage diversion, is dependent on both dilution and a gradually decreasing internal loading. If the released phosphorus is mainly recycled back to the sediment, through sedimentation, a reduction in phosphorus input to the system may have no significant effect on water quality. Knowledge of the physical and chemical character of sediments and their adsorption-desorption characteristics is important to understanding a lake's response to phosphorus reduction (Bostrom and Pettersson 1982).

The Holland River (Figures 1, 2 and 3) is shallow, eutrophic and behaves as a stagnant reservoir during the summer months (Nicholls and MacCrimmon 1975). During this period, external nutrient inputs are negligible since flows are generally undetectable and sometimes upstream when strong northerly winds blow. With the exception of short periods following storm events, the river flow in either the Holland River or Holland River East Branch was generally less than 0.5 m^3/sec

during the summer of 1982 (Ontario Ministry of the Environment (MOE) unpublished). Below the confluence of the Holland River and Holland River East Branch, the river flows through a broad expanse (2-3 km wide) of peat soil and marsh vegetation dominated by Typha latifolia (Nicholls 1976). The meandering main channel is approximately 100-300 m wide and its estimated flow was approximately 1.0 m^3/sec during the summer of 1982 (MOE unpublished). In 1983, flow rates in the lower Holland River (i.e. downstream from Highway #11) were approximately 30 percent lower (Henry 1985).

Nicholls and MacCrimmon (1975) indicated that agricultural drainage from the highly cultivated Bradford and Holland Marshes was the major source of nutrients to the Holland River (Figure 3), and it remains a significant source. In contrast, the Holland River East Branch received primarily municipally treated sewage from this relatively highly urbanized area. During the past decade, watershed management efforts have concentrated on phosphorus reduction from municipal sources, and by the summer of 1984 all municipal sewage wastes from Newmarket and Aurora were being diverted from the Holland River East Branch to the York-Durham system.

The purpose of this limnological investigation was to provide baseline information on summer trophic conditions in the lower Holland River before nutrient supplies were further reduced by the diversion of municipal sewage discharges out of the basin. Since Nicholls (1976) suggested that sediment inputs caused increases in concentrations of dissolved substances during mid-summer, laboratory and field studies were undertaken to substantiate this claim. This study is part of the Lake Simcoe Environmental Management Strategy (LSEMS) studies of the Ontario Ministry of the Environment and South Lake Simcoe Conservation Authority.

METHODS

Water samples were collected at mid-depth, as described by Nicholls (1976) from Stations III, IV and VI (Figure 3) during the ice-free periods of 1982 and 1983. In addition, Cook Bay (Station VIII) was sampled during 1983. Chemical analyses for phosphorus, nitrogen, iron, manganese, and chlorophyll a were performed at the Ontario Ministry of the Environment laboratories in Rexdale. Water temperatures and dissolved oxygen concentrations were measured in the field using a Y.S.I. Model 54 oxygen meter. For a detailed discussion of analytical procedures and sampling containers see "Outlines of Analytical Methods" (MOE 1981).

Experimental Enclosures

In 1982, two experimental enclosures (corrals) were constructed at Station V to investigate phosphorus regeneration in a closed system, and the importance of zooplankton biomass on phosphorus cycling. The cylindrical enclosures (inside diameter 3.9 m) consisted of a double layer of 6 ml polyethylene sheeting which was fastened to a wooden frame at the surface and extended approximately 15 cm into the sediment. Corral I remained untreated and Corral II was treated bi-weekly with a 5 percent concentration of rotenone to eliminate its zooplankton population.

Zooplankton and water samples were collected bi-weekly. Water samples were collected at 1 m and 10 cm above the bottom and analyzed as described above. Relative zooplankton biomasses at Station V and in the neighbouring corrals were estimated by quantitatively pooling zooplankton samples using a wide-mouth pipette. Biomass estimates were calculated by identifying and counting each zooplankton species (Appendices A and B) and using reported dry weights from the literature (Hitchin and Yan 1983, Lawrence et al. 1980). Dry weight values for a few species were not available.

Sediment Cores

Sediment cores (approximately 40 cm long) and overlying river water were collected from the lower Holland River at Stations III and IV, respectively. The two cores were collected in plexiglass tubes (inside diameter 7.6 cm), brought to the laboratory and incubated in the dark. Each tube contained about 5 litres of water. Water temperatures and dissolved oxygen concentrations were monitored continuously using Y.S.I. Model 56 oxygen meters. At the beginning of the experiment (October 6, 1982) and after one week, water samples were collected and analyzed for phosphorus and nitrogen compounds.

Calculations and Statistics

Water samples with non-detectable nutrient concentrations were assigned the detection limit (MOE 1981) for calculating seasonal means and standard deviations. All statistical comparisons are based on the Student t-test. Data collected during 1971, and used in comparison with water quality parameters measured in 1982 and 1983, were previously reported by Nicholls and MacCrimmon (1975). Percent increases or decreases in mean nutrient concentration were calculated as a percentage change defined as $(X_F - X_O / X_O)$ 100.

RESULTS AND DISCUSSION

Water quality parameters monitored in the lower Holland River during 1982 and 1983 provide background information, prior to municipal sewage diversion, on summer trophic conditions and nutrient gradients (Table 1). Chlorophyll *a* concentrations were generally highest at Station IV (Figure 4). Mean corrected chlorophyll *a* concentrations at Station IV were 45 $\pm$ 7 µg/L and 50 $\pm$ 34 µg/L in 1980 and 1983, respectively. While in Cook Bay (Station VIII), the mean corrected chlorophyll *a* concentration in 1983 was 4 $\pm$ 4 µg/L.

In 1982 and 1983, mean total phosphorus (P) concentrations were also higher at Station IV than at Station III (Table 1). The Holland River East Branch recorded a mean total P concentration of 415 ± 181 µg P/L in 1983. Although the mean soluble reactive P concentration was slightly higher in the Holland River during 1982 (129 µg P/L), the Holland River East Branch produced a higher mean soluble reactive P concentration in 1983 (215 µg P/L). Both total and soluble reactive P concentrations were relatively low near the river mouth (Station VI). In 1983, mean total and soluble reactive P concentrations in Cook Bay were 50 and 16 µg P/L, respectively.

Nitrogen concentrations fluctuated considerably throughout the sampling periods of 1982 and 1983 (Figure 5). Mean total nitrogen and nitrate-N concentrations were significantly higher in the Holland River East Branch than the Holland River ($P < 0.01$). In 1982, the Holland River East Branch had the highest mean concentrations of total N (3599 µg/L) and nitrate-N (1341 µg/L) found in this study (Table 1). Mean nitrite-N and ammonia-N concentrations were also highest at Station IV during both years. In 1982, the lowest mean concentrations of nitrate-N (436 µg/L), nitrite-N (16 µg/L) and ammonia-N (123 µg/L) were measured in the Holland River. However, mean concentrations of nitrogen compounds were lowest at Station VI in 1983.

Since the introduction of nutrient control measures and detergent-P legislation in 1971, improvements in water quality throughout the lower Holland River were apparent at Stations III, IV, VI and VIII (Table 1). Mean concentrations of total P, soluble reactive P and corrected chlorophyll *a*, for the period May through October, were significantly lower in 1982 in comparison to water samples collected during 1971 ($P < 0.05$). In 1982, the reduction in mean concentrations of total P, soluble reactive P, and corrected chlorophyll *a* for the lower Holland River stations ranged from 40 - 52%, 49 - 56%, and 25 - 69%, respectively (Table 2).

In 1983, mean soluble reactive P concentrations for the lower Holland River stations were not significantly lower than those recorded in 1971. Total P concentrations were significantly lower at Stations III

($P < 0.01$) and VI ($P < 0.05$), and corrected chlorophyll *a* concentrations were significantly lower at Stations III and IV ($P < 0.01$). The percent reductions in mean concentrations of total P, soluble reactive P and corrected chlorophyll *a* for the lower Holland River stations ranged from 28 - 45%, 7 - 39%, and 45 - 66%, respectively (Table 2). Mid-summer phosphorus maxima were higher in 1971 than those recorded in both 1982 and 1983 (Figure 6).

In comparison to the summer of 1971, total and soluble reactive P concentrations were markedly lower in Cook Bay during 1983 (Figure 6). The total phosphorus maxima observed in 1971 and 1983, were 750 and 250 µg P/L, respectively. The lower mean concentrations of total P ($P < 0.01$) and soluble reactive P ($P < 0.05$), correspond to 75 and 86 percent reductions, respectively (Tables 1 and 2).

Mean nitrate concentrations were significantly higher at Stations III and IV during both 1982 and 1983, and Station VI during 1982 ($P < 0.01$). Nitrite and ammonia-N concentrations increased significantly ($P < 0.01$) between 1971 and 1983 (Table 1). These results coincide with the improved trophic conditions in the lower Holland River, assuming that the increases are a result of reduced algal demand and/or enhanced biological nitrification and ammonification processes. The data suggest improved aerobic conditions and redox potential throughout this system. Data are not available to assess directly whether total nitrogen inputs have increased during the past decade.

It is well known that phosphorus is released from the sediments under anaerobic conditions. However, increases in lake phosphorus levels from sediments in contact with well aerated water can be substantial in shallow sewage-loaded lakes (Knoblauch 1982, Bostrom *et al.*1982, Bostrom and Petersson 1982, Stevens and Gibson 1977, Ryding and Forsberg 1977). Aerobic phosphorus release is important in shallow non-stratified lakes, since the P can be dispersed to the whole water column and continuously supply the productive layer instead of being trapped below a thermocline. In shallow lakes (i.e. 5m), every biotic and abiotic process which mobilizes phosphorus in the sediment and every mechanism which transports this P to the lake water, such as

wind-induced turbulence, bioturbation and diffusion, can potentially contribute to the overall P release (Bostrom et al. 1982, Bostrom and Petersson 1982, Reynoldson and Hamilton 1982, Gardner et al. 1981, Holdren and Armstrong 1980, Petr 1977, Ryding and Forsberg 1977, Charlton 1975, Lean et al. 1975). The biological, physical, and chemical processes involved in the cycling of phosphorus and the interrelationship among the various processes makes them difficult, if not impossible, to evaluate separately (Doremus and Clesceris 1982, Lehman 1980). However, by comparing net changes in nutrient levels with physical and chemical conditions in the aquatic system, one can indicate the conditions prevailing when high sediment release is observed.

Many factors indicate that low redox conditions in the river sediment may be governing the internal P generation and the cause of the seasonal phosphorus peaks observed in the lower Holland River during 1982 and 1983. Low dissolved oxygen conditions (5 mg/L) and relatively high water temperatures (21-23°C), above the sediment and measured around mid-day, coincide with the period of peak phosphorus levels observed during mid-July to mid-August at Stations III, IV, VI and the enclosure site (Station V) in 1982 (Figures 6, 7, 9 and 10). In addition, a supplementary visit to the Holland River in early August 1982 (before sunrise), revealed dissolved oxygen concentrations of 2 mg/L or less throughout the entire water column. Similarly, the dissolved oxygen sag (Figure 8) and high water temperatures (23-28°C), recorded at approximately 1 m above the sediment surface, coincide with the peak P levels observed in the lower Holland River during July and August of 1983 (Figure 6). At this time, external nutrient inputs were assumed to be negligible because of stagnant conditions.

Manganese concentrations were elevated during the summer of 1982 from mid-July to September at Stations III, IV, V, and VI (Figures 4 and 11). At the same time, Fe levels were elevated at Stations IV, V and VI. Total iron concentrations were highly variable in 1983. During the summer of 1983, total Mn concentrations were greater than 150 µg/L at Stations III and IV, and greater than 75 µg/L at Station VI

(Figure 4). These elevated levels probably reflect a lowering of the sediment redox potential and the liberation of Mn and Fe from the sediment. It is important to note that water samples collected at Station V, in 1982, revealed a concentration gradient between the upper and lower depths of the water column (Figure 11).

Experimental Enclosures

The use of experimental enclosures at Station V demonstrated the input of phosphorus from the bottom sediments. Furthermore, the inputs appear to be oxidation-reduction (redox) potential controlled. The phosphorus peaks observed in Corrals I and II coincide with the river peaks (Figures 6 and 10). During this period the corrals experienced depressed dissolved oxygen conditions and maximum water temperatures (Figure 9). In July, total phosphorus concentrations at mid-depth increased from 232 µg P/L to 555 µg P/L in Corral I (Figure 10).

Since Fe and Mn compounds exist in a state of dynamic chemical equilibrium, controlled by bacterial activity and chemical oxidation, observed concentration increases within the impoundments indicated internal inputs (Figure 11). Furthermore, Mn and Fe levels were higher in water samples collected 10 cm above the bottom than at mid-depth, suggesting a benthic source of reduced Fe and Mn compounds.

The role of detritivores in the biogeochemical cycling of nutrients in the lower Holland River is presently unclear. In general, an increase in water temperature has an indirect effect by increasing biological activity and dissolved oxygen consumption. High microbial activity may create anaerobic microzones which are rapidly destroyed, but allow iron (III) reduction and associated phosphorus mobilization to proceed under apparently oxidized conditions (Bostrom et al. 1982). Also, organic phosphate mineralization may be enhanced and, if the sediment is phosphorus-saturated, phosphate can be rapidly released to lake water.

Although the results are not definitive, phosphate regeneration by zooplankton excretion does not appear to be important at the zooplankton densities found in the lower Holland River and the experimental enclosures. Phosphorus concentrations in Corral I and the control site were similar (Figure 10) . Mean total P concentrations at mid-depth for Corral I and Station V were 332 µg P/L and 318 µg P/L, respectively (Table 3). Seasonal total P maxima at mid -depth were also similar in Corral I (555 µg P/L) and Station V (660 µg P/L). However, the zooplankton biomass in Corral I was approximately three times higher (Table 4). In addition, Corral II exhibited a moderately high zooplankton biomass, despite the rotenone treatments, and markedly lower mean concentrations of total P and soluble reactive P at mid-depth. Phosphorus concentrations immediately above the sediment surface were generally lower in the corrals than at the control site. The mean total P concentration at the bottom was significantly lower in Corral I than at the control site ($\underline{P} < 0.01$).

In comparison to Corral I, the altered phosphorus profile of Corral II, and the relatively higher total and soluble reactive P concentrations above the sediment surface during July (Figure 10), probably resulted from the deposition and compartmentalization of P between microorganisms and the closely associated detrital material at the sediment (Doremus and Clesceris 1982). Although detritivores mobilize P through excretion and burrow pumping, a significant quantity of P can be adsorbed and cycled within the microbial-detrital complex or become sequestered in ferric hydroxide compounds. Also, the sediment redox potential may be sufficiently reduced, through energy input from sedimenting organic material, causing organic matter to be less microbially active and less efficiently mineralized by anaerobic metabolism. These phenomena can cause phosphorus to accumulate in the sediment.

Sediment Cores

Intact sediment cores taken from the Holland River and Holland River East Branch demonstrate the potential for phosphorus regeneration under dissolved oxygen conditions of less than 1 mg/L in the overlying water (Figure 12). After 6 days, dissolved total P concentrations in the Holland River and Holland River East Branch experimental tubes were 525 µg P/L and 420 µg P/L, respectively. At the same time, soluble reactive P concentrations were approximately 325 µg P/L in each tube. The Holland River East Branch experimental tube exhibited anaerobic metabolism (denitrification). In contrast, the Holland River core exhibited a lower dissolved oxygen demand and the aerobic process, nitrification, was evident.

Combined with the previous results, this laboratory experiment indicates that under certain environmental conditions the Holland River and Holland River East Branch sediments can serve as P sources to the overlying water. The relatively greater potential for total phosphorus regeneration exhibited by the Holland River East Branch sediment coincides with the higher mean concentrations of total P, Fe ($P < 0.01$) and Mn ($P < 0.10$) found in the lower Holland River during 1982 (Table 1).

CONCLUSIONS

Temporal and spatial changes in water quality parameters monitored in the lower Holland River during the summers of 1982 and 1983 provide valuable information on trophic conditions and nutrient gradients. Concentrations of chlorophyll a, phosphorus, nitrogen, iron, and manganese were generally highest in the Holland River East Branch and lowest near the river mouth. Annual variations in mean summer concentrations of phosphorus, iron and manganese probably depend on environmental factors controlling the onset of stagnant conditions and depressed dissolved oxygen levels.

During the summer months, the lower Holland River sediments can serve as a phosphorus source to the overlying water. Internal phosphorus supplies were demonstrated by monitoring ambient concentrations of dissolved substances in both the lower Holland River and water impounded from the river by experimental enclosures. Although oxidation-reduction conditions in the river are unknown, temperature increases and lowered dissolved oxygen conditions probably lead to increased dissolved P concentration.

Since the introduction of phosphorus control measures, substantial phosphorus reductions have occurred in the lower Holland River and Cook Bay during the past decade. The diversion of Newmarket and Aurora municipal waters will further reduce phosphorus levels in the Holland River East Branch. However, it is important to realize that the sewage diversion will also reduce the flow of the Holland River as a whole. This could result in longer periods of stagnation during the summer months, and consequently result in greater internal loading of phosphorus from the river sediments. The net effect on Cook Bay could be a delay in the expected water quality improvements from reduced phosphorus loading.

Future studies are essential to clarify the fate of mid-summer phosphorus accumulations in the lower Holland River and their impact on Cook Bay. A complicating feature of Cook Bay is that the bay experiences a certain amount of water exchange with the lower Holland River and Lake Simcoe when strong northerly winds prevail (Nicholls and MacCrimmon 1975). The extent of nutrient transport and exchange is unknown for the predominantly stagnant summer period.

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Table 1 Summary of water quality data ($\bar{x} \pm$ S.D.) collected from May through October of 1971, 1982 and 1983 (sample size in parentheses)

PARAMETER	STATION III	STATION IV	STATION VI	STATION VIII
Corrected Chlorophyll a (µg/L)				
1971	76 ± 38 (13)	147 ± 98 (12)	51 ± 45 (12)	26 ± 18(13)
1982	36 ± 26 (13)	45 ± 7 (13)	38 ± 32 (14)	
1983	33 ± 15 (21)	50 ± 34 (23)	28 ± 21 (22)	4 ± 4(19)
Total P (µg/L)				
1971	537 ± 281 (13)	537 ± 333 (13)	361 ± 215 (13)	201 ± 207(13)
1982	256 ± 163 (14)	302 ± 104 (15)	218 ± 142 (14)	
1983	295 ± 162 (22)	415 ± 181 (20)	231 ± 131 (23)	50 ± 50(21)
Soluble Reactive P (µg/L)				
1971	293 ± 207 (13)	231 ± 194 (13)	197 ± 171 (13	111 ± 152(13)
1982	129 ± 136 (14)	115 ± 91 (15)	101 ± 114 (14)	
1983	178 ± 118 (23)	215 ± 132 (23)	130 ± 93 (23)	16 ± 28(21)
Nitrate-N (µg/L)				
1971	31 ± 72 (13)	207 ± 304 (13)	100 ± 209 (13)	12 ± 6(13)
1982	436 ± 392 (14)	1341 ± 1036 (15)	496 ± 410 (15)	
1983	265 ± 315 (21)	971 ± 746 (22)	241 ± 385 (22)	20 ± 37(21)
Nitrite-N (µg/L)				
1971	3 ± 7 (13)	21 ± 34 (13)	3 ± 5 (13)	1 ± 1(13)
1982	16 ± 19 (14)	80 ± 141 (15)	28 ± 31 (15)	
1983	53 ± 80 (21)	93 ± 123 (23)	28 ± 48 (23)	5 ± 8(21)
Ammonia-N (µg/L)				
1971[1]	47 ± 75 (11)	65 ± 124 (11)	25 ± 39 (11)	16 ± 18(11)
1982	93 ± 151 (15)	207 ± 362 (16)	149 ± 270 (16)	
1983	267 ± 207 (23)	353 ± 485 (23)	172 ± 172 (23)	49 ± 38(21)
Total N (µg/L)				
1982	1980 ± 502 (14)	3599 ± 1198 (15)	1894 ± 493 (15)	
1983	1836 ± 413 (21)	2940 ± 1215 (22)	1456 ± 482 (22)	562 ± 207(21)
Total Fe (µg/L)				
1982	406 ± 347 (14)	872 ± 308 (15)	325 ± 172 (15)	
1983	409 ± 146 (23)	1183 ± 397 (23)	273 ± 151 (23)	55 ± 36(21)
Total Mn (µg/L)				
1982	94 ± 38 (14)	117 ± 31 (15)	70 ± 30 (15)	
1983	98 ± 26 (24)	131 ± 30 (23)	69 ± 25 (24)	15 ± 11(22)

[1]Sampling period is June 2 to October 20

Table 2 Percentage change in mean concentrations of various water quality parameters. The 1982 and 1983 values represent percent increases or decreases since 1971.

PARAMETER	STATION III	STATION IV	STATION VI	STATION VIII
Corrected Chlorophyll a				
1982	-53	-69	-25	
1983	-57	-66	-45	-85
Total P				
1982	-52	-47	-40	
1983	-45	-28	-36	-75
Soluble Reactive P				
1982	-56	-50	-49	
1983	-39	- 7	-34	-86
Nitrate-N				
1982	1306	548	396	
1983	845	369	141	67
Nitrite-N				
1982	433	281	833	
1983	1667	342	833	400

Table 3 Summary of water quality conditions ($\bar{x}$ ± S.D.) at Station V and the corrals (sample size in parentheses).

PARAMETER	STATION V (Control)	CORRAL I	CORRAL II (Rotenone added)
Total phosphorus (µg/L)			
1 m	318 ± 155 (11)	332 ± 115 (11)	281 ± 68 (11)
bottom	386 ± 153 (11)	249 ± 71 (11)	297 ± 136 (11)
Soluble Reactive P (µg/L)			
1 m	142 ± 141 (11)	196 ± 140 (11)	129 ± 93 (11)
bottom	156 ± 163 (11)	137 ± 59 (11)	161 ± 122 (11)
Total Mn (µg/L)			
1 m	102 ± 33 (11)	45 ± 13 (11)	50 ± 22 (11)
bottom	137 ± 33 (6)	72 ± 40 (8)	80 ± 43 (7)
Total Fe (µg/L)			
1 m	601 ± 218 (11)	233 ± 81 (11)	221 ± 175 (11)
bottom	782 ± 201 (6)	317 ± 101 (8)	320 ± 218 (7)
NO_3-N (µg/L)			
1 m	267 ± 285 (11)	276 ± 298 (10)	306 ± 458 (10)
bottom	499 ± 364 (11)	395 ± 438 (11)	244 ± 252 (11)
Corrected Chlorophyll *a* (µg/L)			
1 m	40 ± 33 (10)	20 ± 12 (10)	27 ± 20 (9)

Table 4 Comparison of mean zooplankton numbers and mean biomass estimates for Station V and the experimental enclosures. Each value represents a vertical net haul, which was towed from 0.5 m above the sediment surface to the surface, and assumes 100 percent net efficiency (80 µm mesh). Samples were collected from June 24 to October 6, 1982 (n=9).

LOCATION	NUMBER OF ORGANISMS per cm^2	BIOMASS (µg) per cm^2
Station V (control)	219	75
Corral I	302	248
Corral II (Rotenone added)	303	153

Figure 1: Location of Lake Simcoe and its drainage basin (diagonal lines) relative to the Great Lakes.

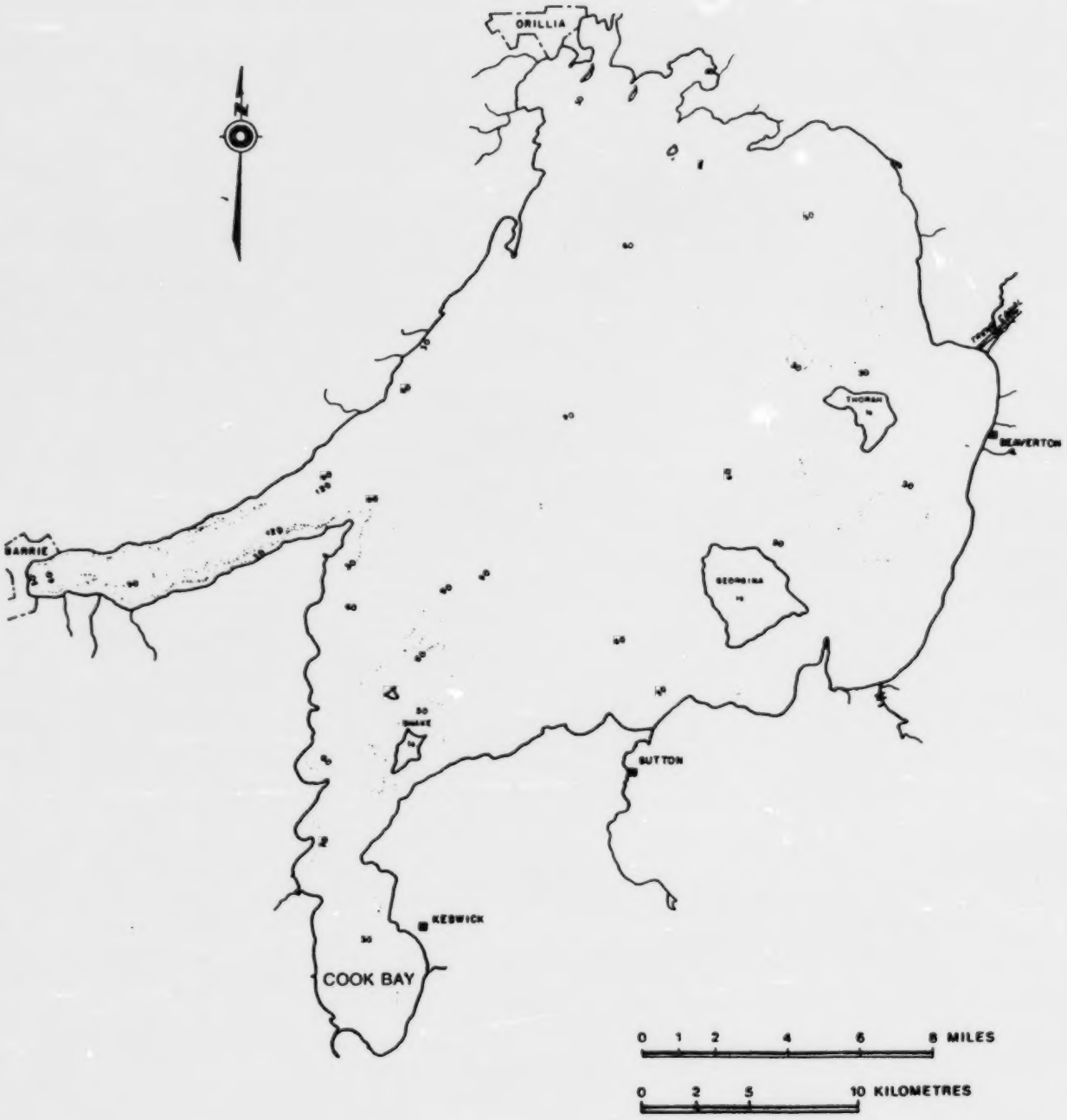
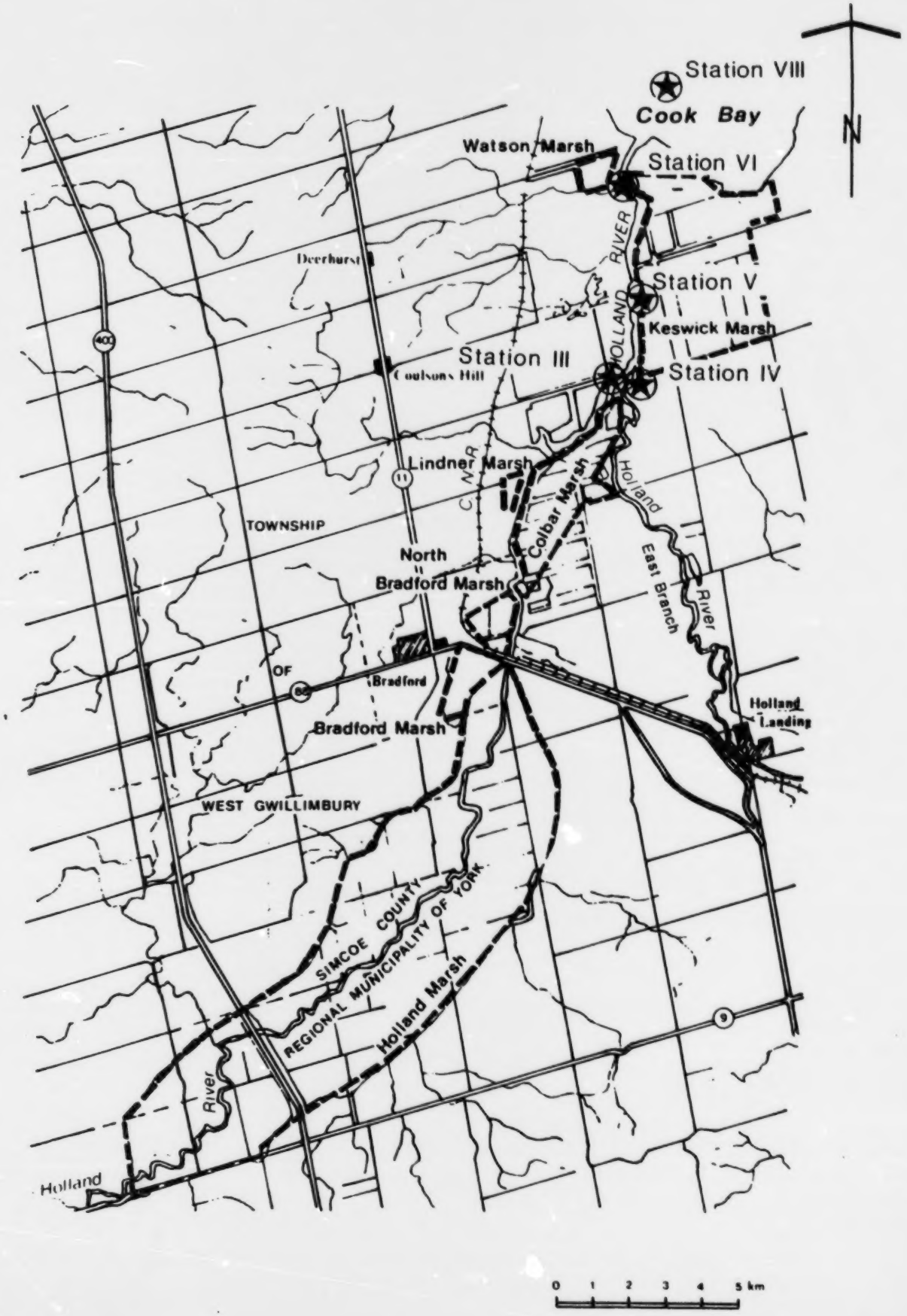


Figure 2: Morphometry of Lake Simcoe (soundings in feet).


Station VIII
Cook Bay
Watson Marsh
Station VI
Deerhurst
HOLLAND RIVER
Station V
Keswick Marsh
400
Station III
Coulsons Hill
Station IV
Lindner Marsh
C N R
Holland
Colbar Marsh
TOWNSHIP
North
Bradford Marsh
East Branch
River
OF
Bradford
Holland
Landing
Bradford Marsh
WEST GWILLIMBURY
SIMCOE COUNTY
REGIONAL MUNICIPALITY OF YORK
Holland Marsh
River
Holland
N
0 1 2 3 4 5 km

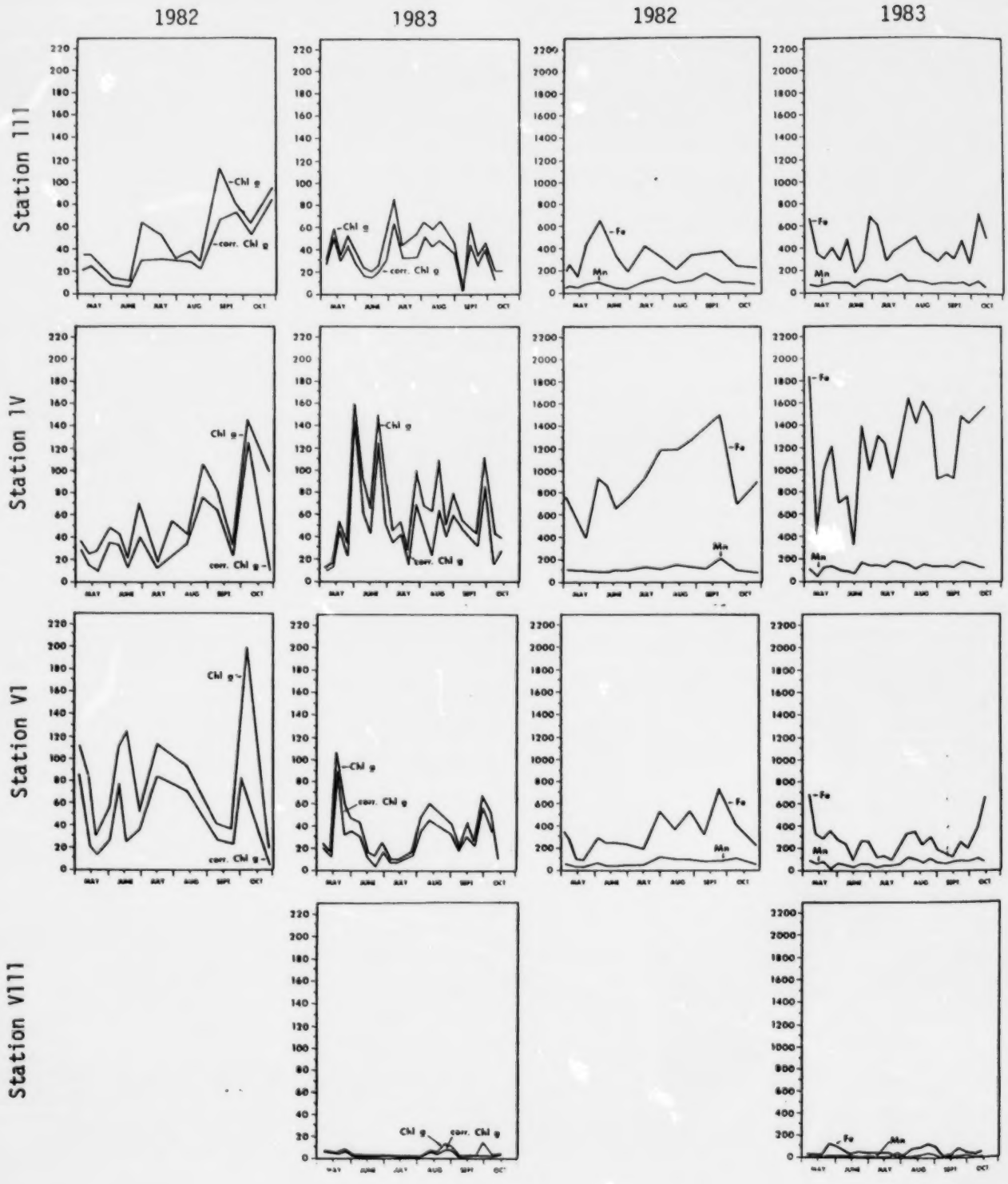


Figure 4: Seasonal concentrations of chlorophyll a, total iron and manganese during 1982 and 1983 (all units in µg/L).

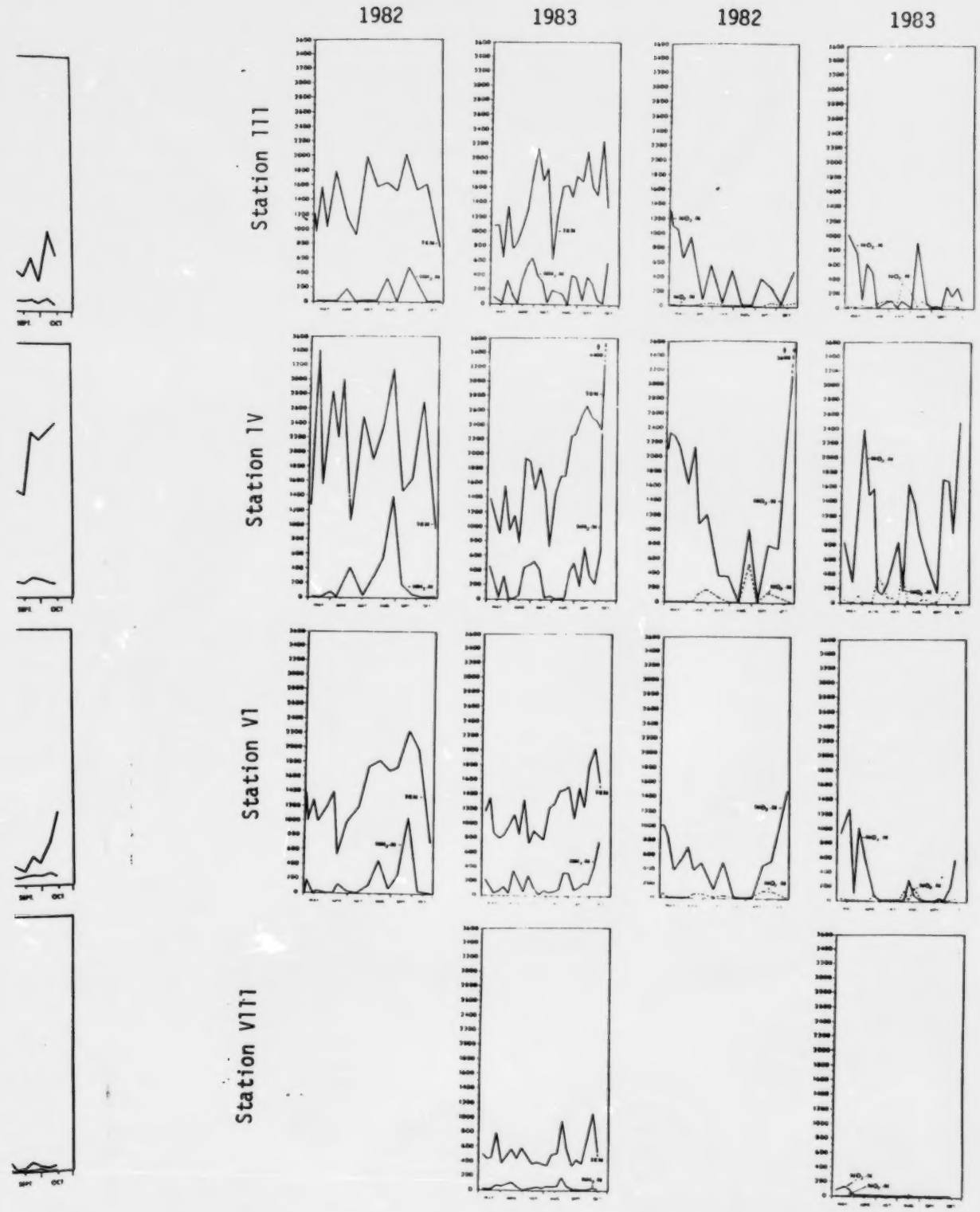


Figure 5: Seasonal concentrations of total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen during 1982 and 1983 (all units in µg/L).

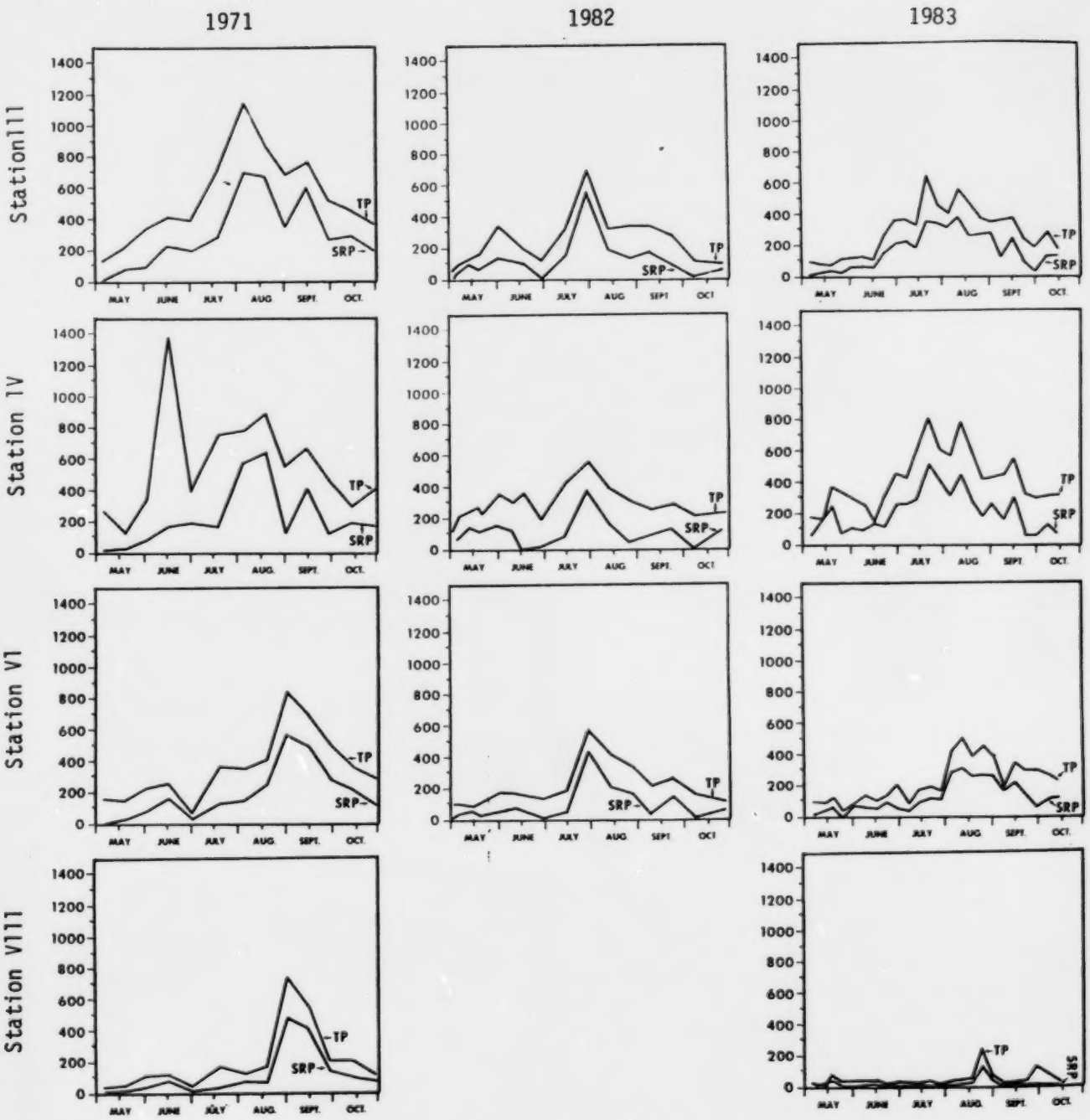


Figure 6: Seasonal variations of total phosphorus and soluble reactive phosphorus concentrations during 1971, 1982 and 1983 (all units in µg/L).

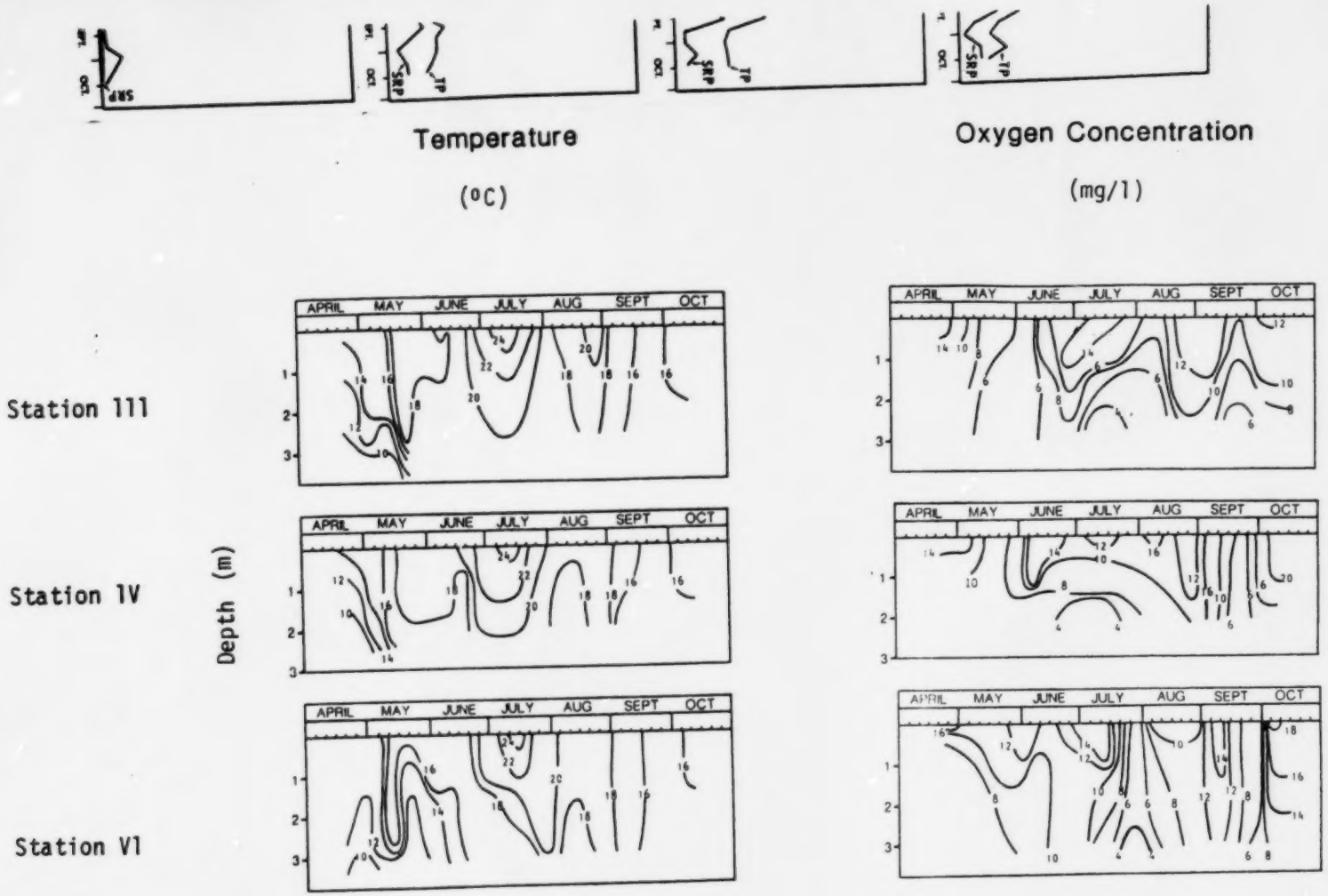


Figure 7: Depth profiles of dissolved oxygen concentrations and water temperatures at Stations III, IV and VI in 1982.

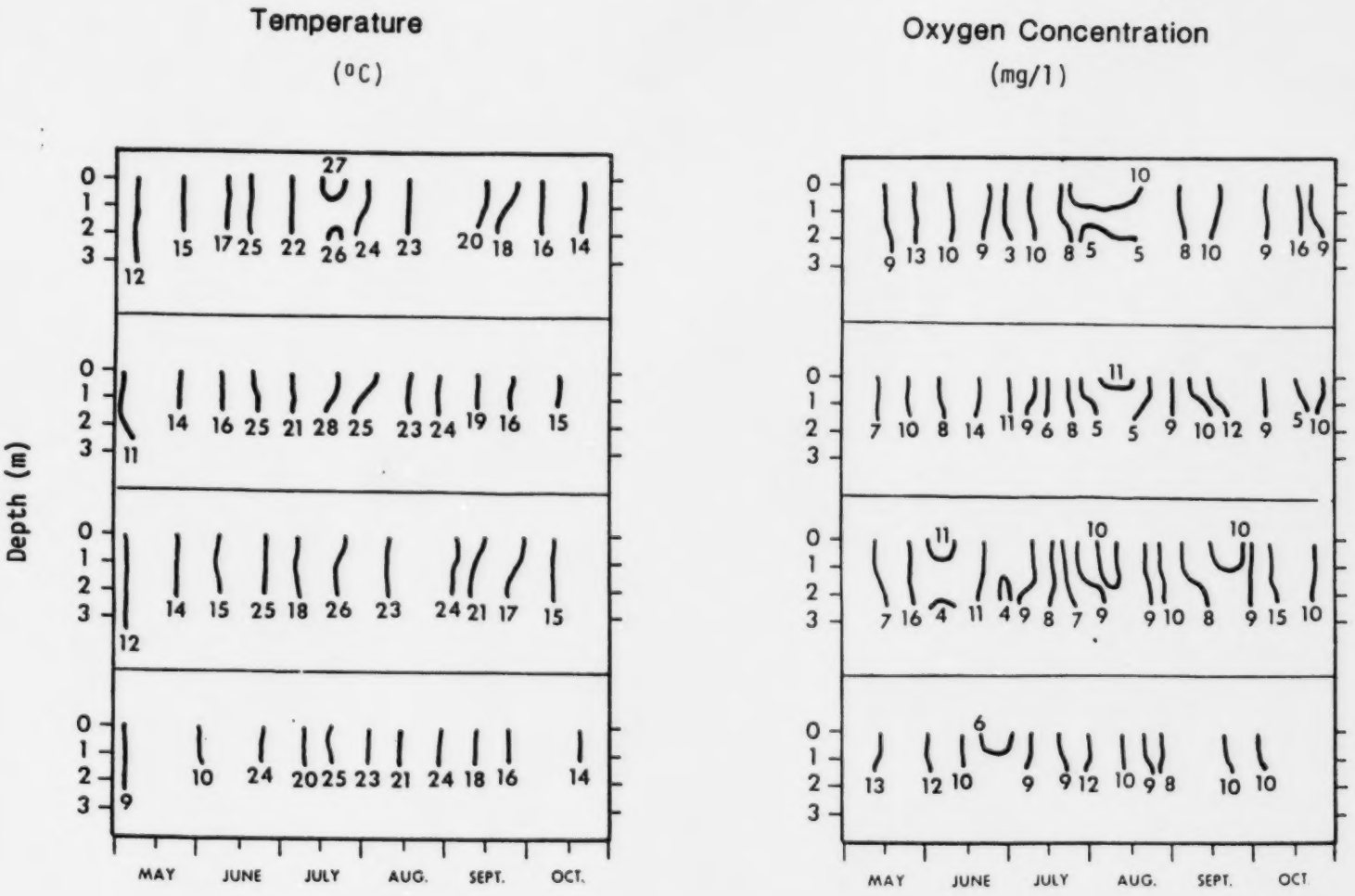


Figure 8: Depth profiles of dissolved oxygen concentrations and water temperatures at Stations III, IV, VI and VIII in 1983.

temperatures at Stations III, IV, VI and VIII in 1983.

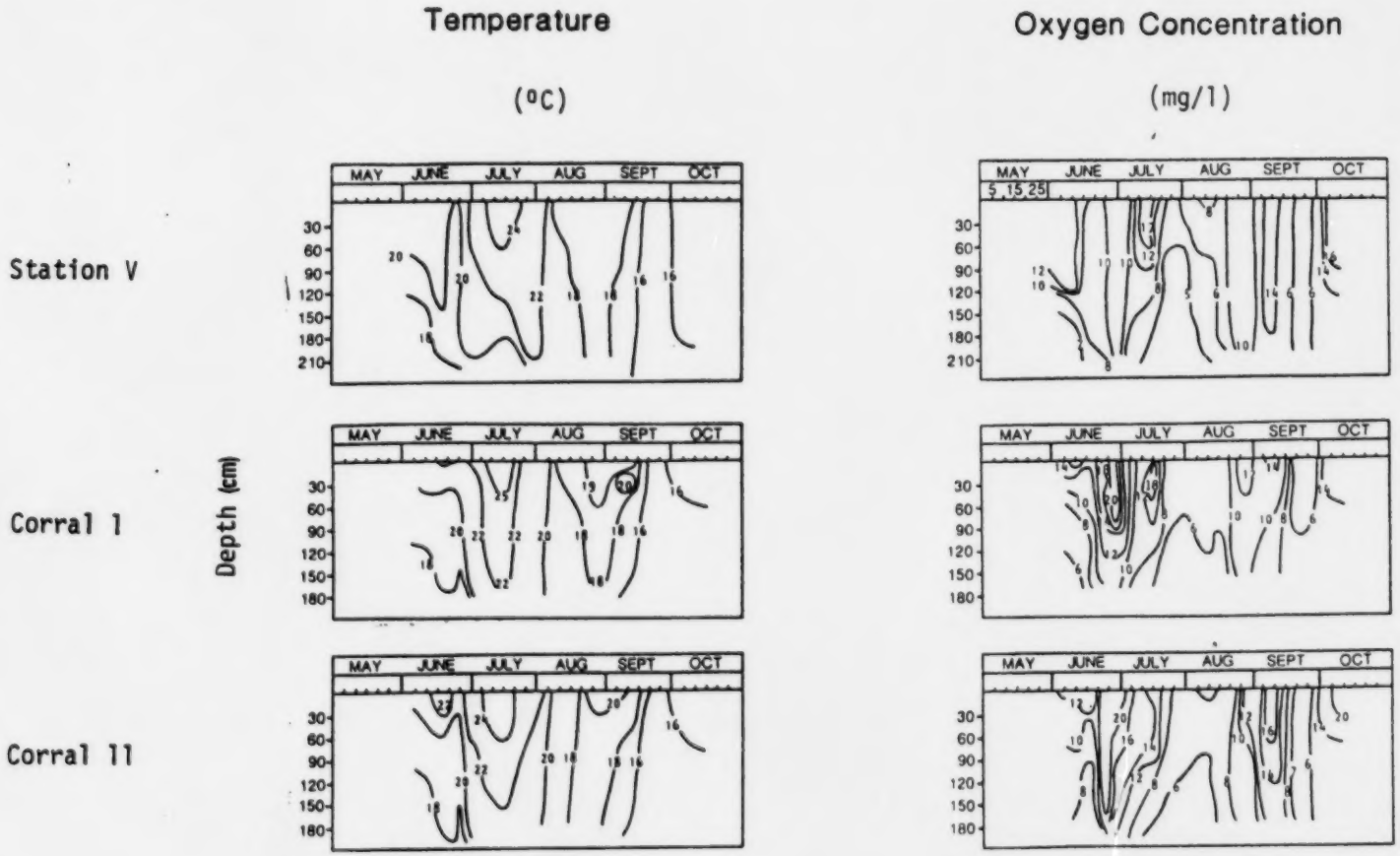


Figure 9: Depth profiles of dissolved oxygen concentrations and water temperatures at Station V and in the experimental enclosures.

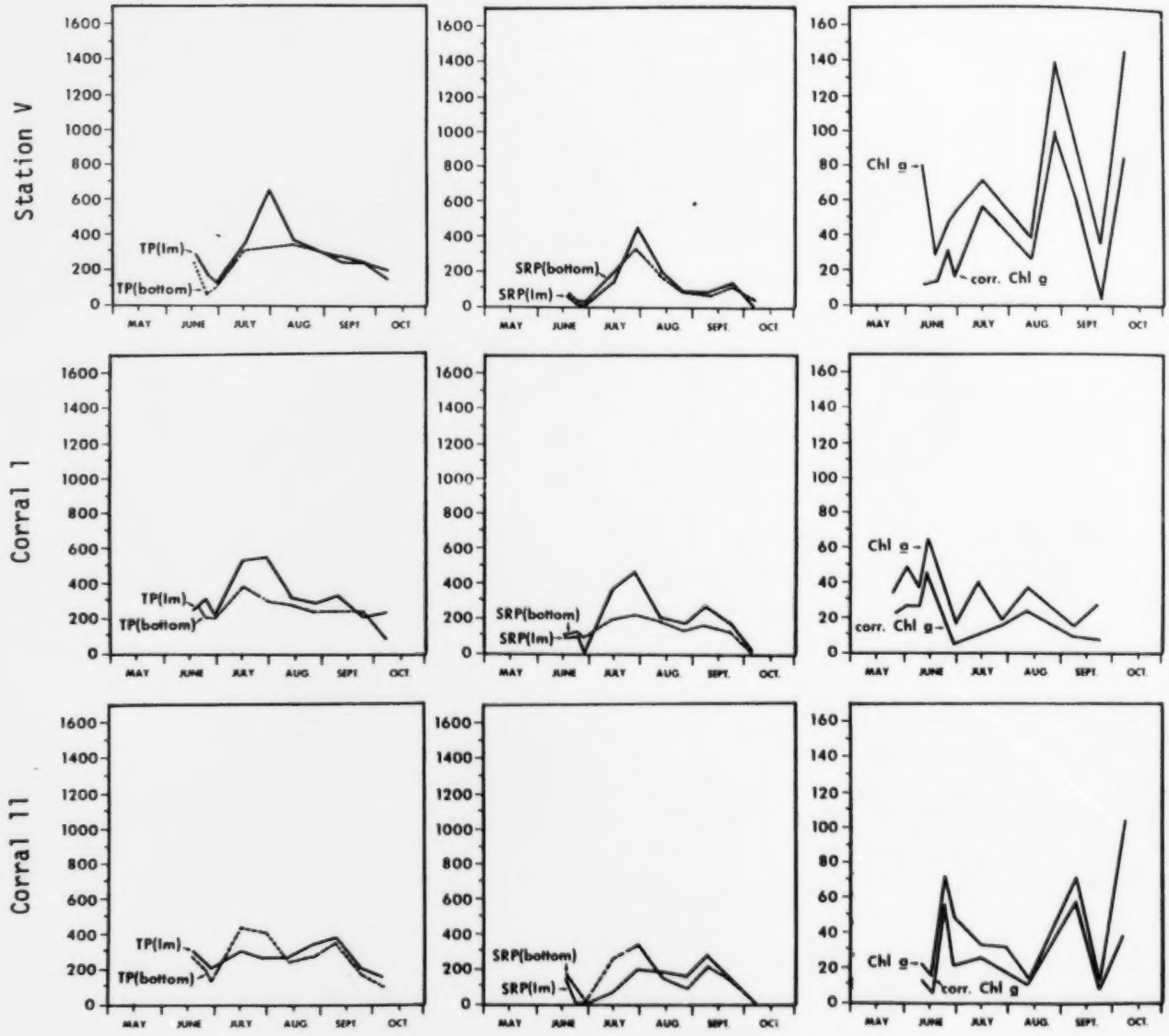
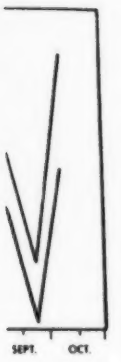


Figure 10: Concentrations of total phosphorus, soluble reactive phosphorus and chlorophyll a in the lower Holland River (Station V), Corral I and the rotenone treated Corral II during 1982 (all units in µg/L).



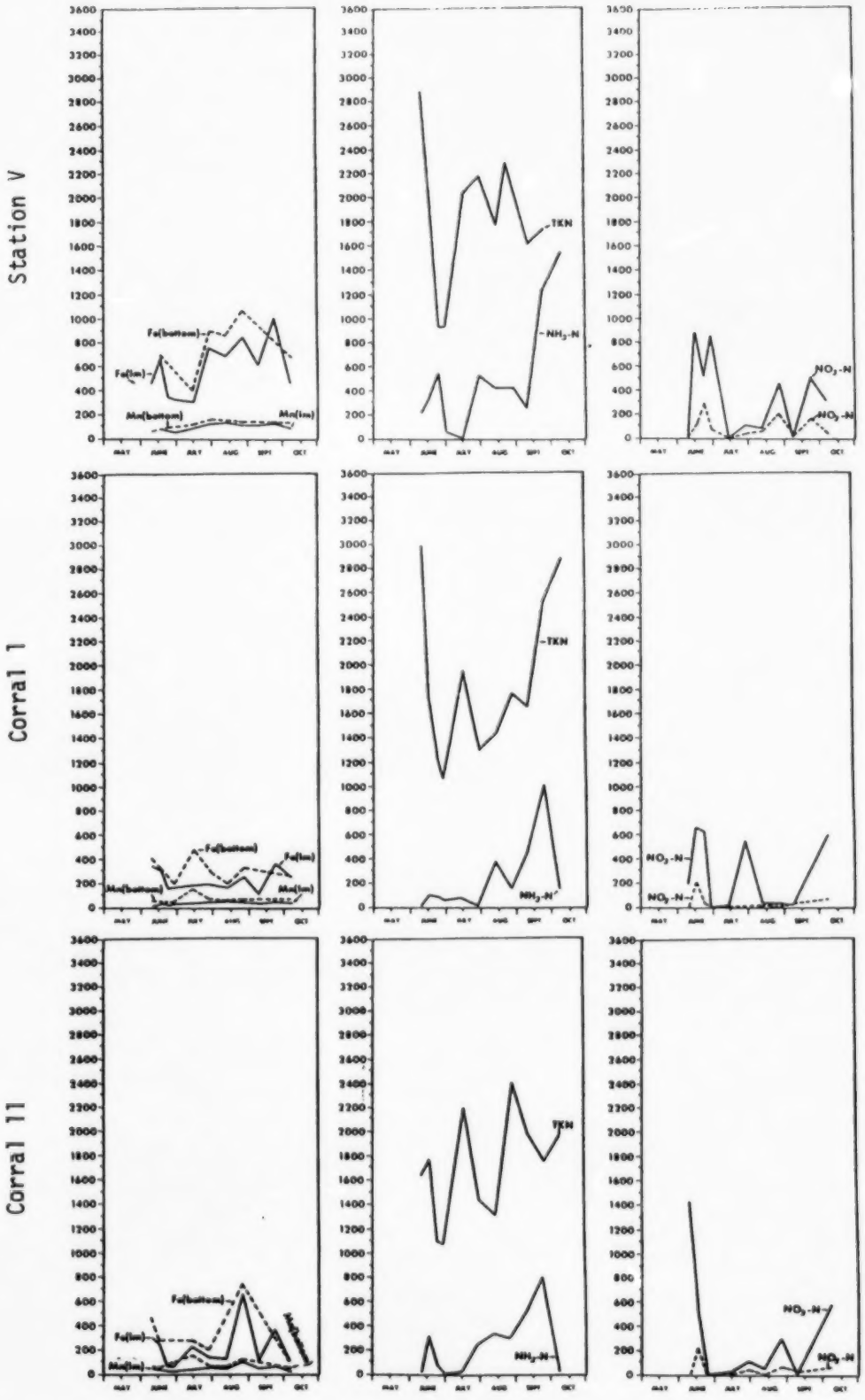


Figure 11: Concentrations of total iron, manganese, Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen in the lower Holland River (Station V), Corral I and Corral II during 1982 (all units in µg/L).

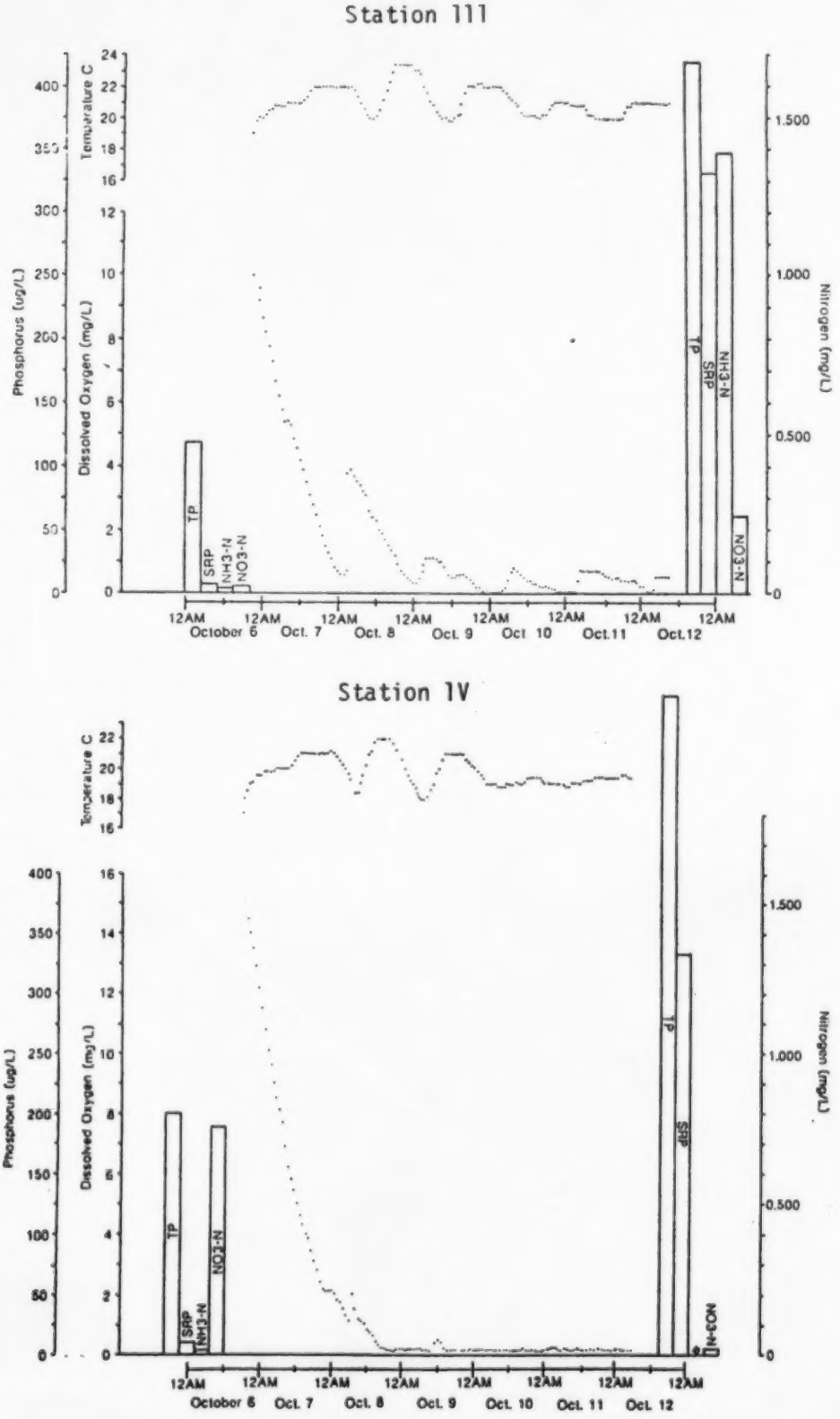


Figure 12: Temperatures, dissolved oxygen and nutrient concentrations in the overlying waters of the intact sediment cores taken from Station III and Station IV of the lower Holland River in 1982.

Appendix A Zooplankton counts in the experimental enclosures and the lower Holland River in 1982.

	CORRAL I	CORRAL II	STATION V
Cyclops vernalis	193	158	84
Copepodids	165	236	78
Mesocyclops edax	3	9	1
Diaptomus sp.	0	1	0
Nauplii	443	777	508
Bosmina longirostris	1312	315	279
Eubosmina coregoni	5	1	3
Ceriodaphnia lacustris	31	8	6
Daphnia longiremis	20	20	2
Daphnia parvula	18	8	2
Daphnia pulex	10	-	-
Dahpnia galeata mendotae	50	9	4
Moina	28	9	19
Chydonis sphaericus	3	0	5
Scapholeberis	1	0	0
Alona quadranguloris	0	1	0
A. rectangula	0	1	0
Polyarthra	306	435	384
Keratella cochlearis	42	193	171
Keratella quadrata	9	31	7
Notholca	13	52	67
Conochilus	78	71	33
Synchaeta	50	215	164
Asplanchna	17	76	38
Brachionus	43	237	214
Filinia	1	4	3
Kellicottia	0	1	0
Monostyla	0	1	0
Lecane	0	1	1
Ostracoda	7	0	3
Total for a 10 ml. aliquot	2874	2884	2080

Appendix B Zooplankton biomass estimates for the experimental enclosures and the lower Holland River in 1982.

	CORRAL I (µg)	CORRAL II (µg)	STATION V (µg)
Cyclops vernalis	606.02	496.12	263.76
Copepodids	247.50	354.00	117.00
Mesocyclops edax	19.38	58.14	6.46
Nauplii	48.73	85.47	55.88
Bosmina longirostris	708.48	170.10	150.66
Eubosmina coregoni	11.00	2.20	6.60
Ceriodaphnia lacustris	15.50	4.00	3.00
Daphnia galeata mendotae	438.00	78.84	35.04
Daphnia longiremis	100.00	100.00	10.00
Daphnia parvula*	56.52	25.12	6.28
Daphnia pulex	80.09	0.00	0.00
Chydonis sphaericus	2.70	0.00	4.50
Polyarthra sp.	10.40	14.79	13.06
Keratella cochlearis	0.42	1.93	1.71
Keratella quadrata	0.225	0.78	0.18
Notholca sp.	0.26	1.04	1.34
Conochilus	0.156	0.142	0.066
Synchaeta	8.00	34.40	26.24
Asplanchna	6.63	29.64	14.82
Total (µg) for a 10 ml. aliquot	2360.01	1456.71	716.60

* Used dry weight of D. retrocurvo.

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K. Nicholls, Water Resources Branch, Ministry of the Environment

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